Interactive comment on "The Nonequilbrium Thermodynamics of Atmospheric Blocking" *by* Andrew Jensen

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I would like to thank the reviewer for the thorough review of the manuscript. The comments were helpful and will help me improve on any deficiencies in the current version. The comments will also help me to make more concrete the parts you consider speculative.

1. Clarification of the intended (speculative) connection between entropy production and self-sustaining flow (in this case, blocking) regimes. There seems to be some confusion between internal entropy generation and external entropy forcing. It is the latter that is associated with the maintenance of "order", viz dissipative structures that allow a matching amount of entropy to be generated internally and thereby maintain themselves. In other words, blocking highs in this context should be regarded as *or-

dered*, not disordered, flow regimes, which are maintained by a large external entropy sink (in this case, sensible/latent heating from the sea surface at high temperature near the surface, and cooling by radiation at low temperature in the free troposphere) and a matching high rate of entropy production internal to the system. Note that it is by no means obvious that the relevant (ordered) dissipative structures reside inside the high rather than at its margins, so a spatially resolved analysis of the entropy terms would be highly desirable.

Reply: I agree that spatial fields will be helpful here. I will add them in a future version of the manuscript.

I apparently didn't make the my argument and perspective on entropy entirely clear. In a future version of the manuscript I will remedy this. I offer here a summary that I hope alleviates any concerns.

The use of the order/disorder description of entropy isn't necessarily the best way to describe blocking. There are only a few sentences mentioning this in the manuscript and I will modify them in a future version. I will also add a discussion highlighting the differences between equilibrium vs. non-equilibrium thermodynamics in blocking.

For example, in the past blocking has often been viewed as an equilibrium state (Charney, DeVore 1979, etc.) or even a quasi-barotropic state. It can be argued that these approaches aren't necessarily realistic. For example, that blocking is not always necessarily best characterized in this way is evidenced by the strong entropy production in the calculations in the manuscript. The calculations here suggest that blocking is closer to a non-equilibrium steady-state, strongly entropy producing with significant boundary fluxes.

Also, I didn't mean to imply that blocking wasn't coherent. It is. The main ideas in the manuscript have been influenced and motivated by an analogy with the characterization of long-lived coherent vortices as maximum entropy structures, such as occur in two-dimensional turbulence (see Turkington et al. 2001, Bouchett and Sommeria

2002, Sommeria 2005). Under certain conditions, including maximum entropy, these vortices can be anticyclonic. Blocking is long-lived with a characteristic lifetime of ~10 days with many events more than twice that length so it is long-lived 'coherent vortex'. I chose two such events here. Hence the coherent vortex maximum entropy structure idea. This is an equilibrium concept, while the calculations here suggest that the analogy isn't perfect; but again, it motivated the present study. Again, blocking is closer to a non-equilibrium steady-state, strongly entropy producing coherent vortex with significant boundary fluxes. In a future version of the manuscript I will compare and contrast the two approaches.

2. Anticyclones are also characterised by a large rate of entropy export (inflow of cold air, outflow of warm air) which should be taken into account or at least discusse

Reply: I agree. Not including lateral entropy export is a weakness in the current version of the manuscript. In a future version of the manuscript I will add spatial fields and summary calculations of the lateral entropy transport.

3. More in general, the results obtained from entropy considerations in an open system should be verified against the use of the appropriate Gibbs potential for such a system, to avoid misreading effects from external mass exchanges; blocking highs may persist long enough for a significant portion of their mass to be acquired from or exchanged with the outside

Reply: I will consider this. But my preliminary assessment is that it's beyond the scope of the current manuscript.

4. The quality of the reanalysis data employed must be discussed and validated to show that it is sufficient for the study at hand and for its conclusions to be robust; in particular, it must be borne in mind that third-law (entropy) consideration may lose meaning if the data under consideration are inconsistent with energy conservation, a problem that reanalyses often have; for this reason it might be more appriate to employ data from simulations with energy-conserving models.

C3

Reply: Looking at strictly energy conserving models is beyond the scope of the current manuscript. It's my view that the reanalysis data provides the most realistic values of the variables in the entropy calculations for the current manuscript. However, a different study could consider the effects you mention.

5. Anomalies relevant to the two events discussed should be calculated and shown from climatology valid for periods of the annual cycle matching those of the events.

Reply: This suggestion is worded in a confusing way and I'm not entirely sure what is meant by it. However, I included the variance calculations to suggest the anomalous nature of the variables compared to climatology.

6. While the sketch of Li and Chylek's (2012) derivation by for the entropy production terms seems unnecessary, much more detail is required on their numerical implementation with reanalysis data in order for the results presented to be amenable to reproduction by other scientists and for application to other cases.

Reply: I agree that I need to provide the details. I will add them in a future version of the manuscript.

For example, the surface entropy flux consists of standard variables only.

The only variables that are less standard in the entropy production come from the heating rates. The reanalysis contains temperature tendencies due to friction, moist processes, radiation, etc. These can be converted to heating rates and vertically integrated to calculate the entropy production.

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